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FABRICATION OF PRECISION OPTICS USING AN IMBEDDED REFERENCE SURFACE

BY

James A. Folta (USA)
2262 Hampton Road
Livermore CA 94550

Eberhard Spiller (Germany)
60 Lakeside Road
Mt. Kisco, NY 10549

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to precision mirror fabrication, and more specifically, it relates to techniques for adjusting the figure of a substrate for a precision mirror.

Description of Related Art

Present methods for fabricating precision mirrors are very time consuming and costly. The final figure and finish is obtained using many

iterations and a precision measurement of the figure is required after each polishing step.

In U.S Patent No. 5,957,749, titled "Apparatus For Optical Inspection Of Wafers During Polishing" an optical system is disclosed for the inspection of wafers during polishing which also includes a measurement system for measuring the thickness of the wafer's top layer. The optical system views the wafer through a window and includes a gripping system, which places the wafer in a predetermined viewing location while maintaining the patterned surface completely under water.

U.S. Patent No. 4,018,638, titled "Method Of Reducing The Thickness Of A Wafer Of Fragile Material" is method of reducing the thickness of a wafer of fragile material, e.g., pyroelectric material, by placing the wafer, supported only at its rim, in a holder filled with a non-corrosive liquid.

U.S. Patent No. 4,793,895, titled "In Situ Conductivity Monitoring Technique For Chemical/Mechanical Planarization Endpoint Detection" discloses an apparatus and method for monitoring the conductivity of a semiconductor wafer during the course of a polishing process.

The invention disclosed in U.S. Patent No. 5,081,421, titled "In Situ Monitoring Technique And Apparatus For Chemical/Mechanical Planarization Endpoint Detection" provides an in situ monitoring technique and apparatus for chemical/mechanical planarization end point detection in the process of

fabricating semiconductor or optical devices. The detection in the present invention is accomplished by means of capacitively measuring the thickness of a dielectric layer on a conductive substrate.

In U.S. Patent No. 5,125,740, titled "Method And Apparatus For Measuring Optical Constants Of A Thin Film As Well As Method And Apparatus For Fabricating A Thin Film Utilizing Same", a sample is located so as to be close to a prism and a light beam coming from a light source is projected to the prism while varying the incident angle to the prism as a parameter. Optical constants such as the refractive index, the film thickness, the distribution of the refractive index, etc. are obtained by calculation, starting from measured values thus obtained.

In U.S. Patent 5,157,877, titled "Method For Preparing A Semiconductor Wafer", the polishing of a semiconductor is effected by a method which comprises preparing a finished backing pad by the precision surface machining operation, setting the semiconductor wafer on a wafer holding jig having a template containing at least one wafer-positioning hole fixed on a carrier plate in such a manner that the backing pad enters the positioning hole, and polishing the semiconductor wafer.

U.S. Patent No. 5,240,552, titled "Chemical Mechanical Planarization (Cmp) Of A Semiconductor Wafer Using Acoustical Waves For In-Situ End Point

Detection" describes a method and apparatus for chemically mechanically planarizing (CMP) a semiconductor wafer.

U.S. Patent No. 5,293,216, titled "Sensor For Semiconductor Device Manufacturing Process Control" describes a fiber-optic sensor device for semiconductor device manufacturing process control that measures polycrystalline film thickness as well as surface roughness and spectral emissivity of a semiconductor wafer.

U.S. Patent No. 5,337,015, titled "In-Situ Endpoint Detection Method And Apparatus For Chemical-Mechanical Polishing Using Low Amplitude Input Voltage", discloses an in-situ thickness monitoring/endpoint detection method and apparatus for chemical-mechanical polishing (CMP) of a dielectric layer on a top surface of a semiconductor wafer.

U.S. Patent No. 5,433,651, titled "In-Situ Endpoint Detection And Process Monitoring Method And Apparatus For Chemical-Mechanical Polishing" discloses an in-situ chemical-mechanical polishing process monitor apparatus for monitoring a polishing process during polishing of a workpiece in a polishing machine.

U.S. Patent No. 5,492,594, titled "Chemical-Mechanical Polishing Tool With End Point Measurement Station" discloses a wafer polishing and planarizing tool in which there is incorporated a separate measuring station and

means for moving the wafer and immersing the wafer into the measuring station without removing it from the polishing head.

U.S. Patent No. 5,657,123, titled "Film Thickness Measuring Apparatus, Film Thickness Measuring Method And Wafer Polishing System Measuring A Film Thickness In Conjunction With A Liquid Tank" provides a light interference-type film thickness measuring mechanism that measures a film thickness with light directed onto the bottom surface of a wafer held by a wafer holding head.

U.S. Patent No. 5,658,418, titled "Apparatus For Monitoring The Dry Etching Of A Dielectric Film To A Given Thickness In An Integrated Circuit" discloses detecting the desired etch end point in the dry etching of a structure.

U.S. Patent No. 5,719,495, titled "Apparatus For Semiconductor Device Fabrication Diagnosis And Prognosis" provides a sensor for diagnosis and prognosis of semiconductor device fabrication processes that measures specular, scattered, and total surface reflectances and transmittances of semiconductor wafers.

In U.S. Patent No. 5,739,906, titled "Interferometric Thickness Variation Test Method For Windows And Silicon Wafers Using A Diverging Wavefront", an interferometric apparatus and method are provided for determining a seal thickness and thickness variations of silicon wafers and other window-like optics.

As discussed above, precision mirrors are currently fabricated by using a large number of iterations between polishing/figuring and interferometric metrology of the surface figure. No data on the figure is available during polishing and the process is very time consuming. In some cases, about a day is needed in each iteration just to reach a stable temperature of the optic in the interferometer. Current methods make it very difficult to fabricate mirrors fast enough to provide for the expected number of commercial EUVL steppers that will be needed. In order to accelerate production, it is desirable to connect metrology and polishing more tightly, ideally into a single procedure.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for correcting the figure of a substrate.

It is another object of the invention to apply a figure-correcting layer to a substrate and to adjust the thickness of the figure-correcting layer to obtain a desired figure.

Another object of the invention is to apply a marker layer to a substrate before applying a figure-correcting layer, where the marker layer is sandwiched between the substrate and the figure-correcting layer.

Still another object of the invention is to adjust the thickness of a figure-correcting layer with a beam selected from the group consisting of an electron beam, an ion beam and an electromagnetic beam.

Another object of the invention is to adjust the thickness of a figure-correcting layer with a polishing tool.

Another object of the invention is to simultaneously measure and adjust the thickness of a thickness-correcting layer adherent to a substrate to obtain a desired figure.

Another object of the invention is to measure the thickness of a figure-correcting layer simultaneously at a plurality of points.

These and other objects of the present invention will be apparent to those skilled in the art based on the disclosure herein.

In one embodiment of the present invention, the substrate is measured with a very precise instrument such as an embodiment of the Phase Shifting Diffraction Interferometer disclosed in U.S. Patent No. 5,548,403, titled "Phase Shifting Diffraction Interferometer" and U.S. Patent No. 5,933,236, titled "Phase Shifting Interferometer", both patents incorporated herein by reference. If a figure-correcting layer is made of material that has a different index of refraction from that of the substrate, then the figure-correcting layer may be deposited directly on the substrate surface. If a figure-correcting layer is made of material that has nearly the same index of refraction as that of the substrate, then a marker

layer is deposited onto the substrate and the figure-correcting layer is deposited directly on the marker layer. The thickness of the figure-correcting layer is locally measured and the desired thickness is obtained from the PSDI measurement. Adding the thickness of the figure-correcting layer to the figure of the substrate is readily performed with many commercially available numerical analysis or image processing software products. For example, see a product by Research Systems, Inc. titled "Interactive Data Language" (see http://www.rsinc.com/idl/index.cfm). The local measurement of the figure-correcting layer is accomplished through a variety of methods, including interferometry and fluorescence or ultrasound measurements. Adjustments in the thickness of the figure-correcting layer are made until the top of the figure-correcting layer matches the figure specification.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A illustrates a mirror substrate with an adherent marker layer and a figure-correcting layer.

Figure 1B shows a substrate and an adherent figure-correcting layer.

Figure 2 shows an example of an implementation of the invention, where the thickness-measuring tool comprises one or more fiber optics incorporated into a mechanical polishing tool.

Figure 3 illustrates an embodiment for simultaneously measuring the thickness of the figure-correcting layer while modifying its thickness.

Figure 4 shows an embodiment for measuring the thickness of the figure-correcting layer at a plurality of points simultaneously.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the preferred methodology, the first step is to generate a reference surface and protect its figure from any change during the subsequent polishing/figuring process. In a subsequent step, the top surface is modified until the measured difference between the reference and the real surface is equal to the value calculated from the specification of the optics. This later step requires a process to either add or remove material and to measure locally the thickness of the material added or removed. In the case that the deposition or removal process is well calibrated, it is possible to skip the local thickness measurement.

The optic is figured and polished by standard established methods, to a figure close to the desired one. For typical EUV optics, the figuring might be stopped at figure errors around 5-10 nm. The stopping point is determined by economy. Tighter tolerances in this first step require more efforts, but will reduce the requirement for the subsequent processes. The surface produced and characterized is used as the reference surface.

The reference surface has to be protected from any change in the subsequent figuring/polishing processes. If addition of material is used for the final figuring, the only requirement is that the reference surface remains observable and its distance to the actual surface can be measured. In one embodiment, it is required that the material to be added is different from the material of the substrate. In another embodiment, the reference surface could be marked by the addition of a thin layer of additional material with a different index of refraction. Since the reference surface is protected by burying it under the surface of the figure-correcting layer, the removal of material never affects the reference surface. This can be achieved by first providing a marker layer over the reference surface and then depositing a protective layer over the marker layer that will be modified in thickness to produce the desired figure.

During the final polishing/figuring process, it is only necessary to measure the thickness of the material above the reference surface locally to derive the figure of the optics. There are a large number of methods to measure the thickness of a film with precision in the Angstrom range. Examples are interference between radiation reflected from the reference surface and the top surface of the optics using visible, UV, or x-ray radiation, ultrasound, fluorescence, etc. Many of these methods have considerably higher precision than the metrology to measure the figure of a large optics and the figure errors in the final optics will be the metrology error in the first measurement of the reference surface.

For optical detection, the marking layer should have a similar reflectivity as the top surface to produce maximum interference contrast. For a mirror material with refractive index of 1.5 and reflectivity of 4%, the amount of material imbedded in an index n=1.5 material corresponds to thicknesses of 1.5, 6, 3.5, 4, 3.5, 2.7, and 3.7 nm for Al, Cr, Co, Ni, Ti, Mo, and Si, respectively, of bulk density. Many other materials may be imbedded within the marker material. One could embed the materials by ion implantation or by vacuum deposition. If vacuum deposition and a subtractive figuring process are used, an additional film of glass or other appropriate material can act as the protective layer and provide the material for subsequent figure correction.

No additional marking layer is required for the case that a figure correcting film of a different material is added after measuring the figure of the substrate.

Figure 1A illustrates a mirror substrate **10** with an adherent marker layer **12** and figure-correcting layer **14**. The mirror substrate figure has been measured in an interferometer. In one embodiment, the marker layer **12** has a uniform thickness and conforms to the surface topology of the substrate **10**. Figure-correcting layer **14** adheres to marker layer **12**. The index of refraction of the figure-correcting layer **14** may be identical to that of the substrate when used with the marker layer, but must be different from the index of refraction of the marker layer. The thickness distribution of the figure-correcting layer is adjusted

to provide figure errors to the level required for diffraction-limited performance. Figure 1B shows a substrate **16** and an adherent figure-correcting layer **18**. For an embodiment such as this that has no marker layer, it is required that the substrate **16** have a first index of refraction and the figure-correcting layer **18** have a second index of refraction that is substantially different from that of the first index of refraction. The index of refraction difference provides an interface **17** between substrate **16** and figure-correcting layer **18**. This index difference will generate reflections of electromagnetic and ultrasound waves for use in measuring the thickness of the figure-correcting layer.

Thin films have been used in the past to correct the figure of mirrors by depositing thin films of the desired thickness profile on top of a substrate using evaporation masks. See W. C. Sweatt, J. W. Weed, A. V. Farnsworth, M. E. Warren, M. E. Neumann, R. S. Goeke, and R. N. Shagan, "Improving The Figure Of Very Good Mirrors By Deposition," OSA Trends in Optics and Photonics Vol.4, "Extreme Ultraviolet Lithography", G. Kubiak and D. Kania, Eds. Washington, DC, Optical Soc. Of America, 1996., pp. 149-155. See also C. Tarrio, E. Spiller, C. J. Evans, T. B. Lucatorto, and C. C. V, "Post-Polish Figuring Of Optical Surfaces Using Multilayer Deposition," ibid., pp. 144-148.

However, it is time consuming and requires many iterations to produce the masks for general corrections in 2-D that is described by higher order polynomials.

A deposition process where thickness is measured locally and the local deposition rate or time is adjusted until the desired thickness is found is preferable. Photon, ion, or electron beam activated deposition processes can be used for this purpose. An example is the deposition of a carbon film from the cracking of hydrocarbons. The thickness of the deposited film is in many cases proportional to the total flux; in this case the thickness of the correcting film is simply determined by the total illumination intensity at each location. For local in-situ thickness measurements, one can incorporate the thickness measurement tool within the exposure tool.

The reflectivity from the optics is modulated by interference between the surface and the reference surface. Interference fringes can be observed by tuning wavelength and the thickness of the correcting layer is calculated from the position of the extrema. A very compact sensor that uses optical fibers for the incoming and reflected light can be incorporated into a mechanical polishing tool. Thickness monitors using this principle are commercially available. When figuring by an ion beam is used, the test beam can be focused at the location of the ion beam.

Figure 2 shows an example of an implementation of the invention, where the thickness-measuring tool comprises one or more fiber optics **20** incorporated into a mechanical polishing tool **22**. The optical fiber(s) **20** illuminates the surface of the figure-correcting layer **18** and the interface **17** or

marker layer **12** and sends the reflected signal back to a monochromator or detector for analysis to obtain the local thickness of the correcting layer **18**.

Reflection of ultrasound can be used to measure the thickness of the figure-correcting layer. By measuring the time difference between the two pulses that are obtained from the reflection of a short ultrasound pulse from the top and bottom surface of the figure-correcting layer, the thickness of the figure-correcting layer can be determined.

The concentration of marker material at the surface of the figure-correcting layer can be used to indicate its thickness. Ion beam implantation can be used to control the location and profile of the marker material within the figure-correcting layer. As material is removed, it can be analyzed to determine marker material concentration. The concentration near the surface can be used to obtain the distance to the centroid of the profile.

Fluorescence of soft x-rays or x-rays can be used to indicate the thickness of the figure-correcting layer. The fluorescence signal from the marker material is attenuated in the correction layer and its thickness can be derived from the strength of the signal. This method would be suitable for controlling ion beam figuring.

Figure 3 illustrates the modification of the thickness of the figure-correcting layer. The modification is accomplished an electron, ion, or photon

induced deposition or etching process **24**, and the thickness is monitored with an optical monitor **26**. Other examples techniques useful for thickness determination are x-ray fluorescence from the marker layer where the thickness is determined from the absorption in the correcting layer, or fluorescence from the correcting layer, where the signal increases with the thickness of the correcting layer.

Figure 4 shows an embodiment for measuring the thickness of the figure-correcting layer at a plurality of points simultaneously. In the figure, a collimated beam of light **40** from a monochromatic light source **42** passes through a beamsplitter **44** and is reflected from figure-correcting layer **46** and interface **48**. This reflected light is reflected from beamsplitter **44** onto a two-dimensional detector array **50**.

The foregoing description of the invention has been presented for purposes of illustration and description and is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. The embodiments disclosed were meant only to explain the principles of the invention and its practical application to thereby enable others skilled in the art to best use the invention in various embodiments and with various modifications suited to the particular use contemplated. The scope of the invention is to be defined by the following claims.